# DESIGN AND DEVELOPMENT OF AN ULTRASONIC ELECTROLYZER SYSTEM FOR HYDROGEN PRODUCTION

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***ABSTRACT:*** *Hydrogen is expected to be one of the most important fuels in the near future to meet the problem of energy shortage resources due to the shortage of fossil fuels like oil, coal, natural gas and others. Electrolysis a method of separating elements by pushing an electric current through a compound. It is used to separate hydrogen and oxygen from water. It is one of the easiest and cheapest ways to producing hydrogen. Due to the large hydrogen production cost of traditional methods and the seriousness of storage that led to give interest in the present research to develop and performance a hydrogen production system by using the ultrasonic technique The performance of the hydrogen system was evaluated by carrying experiments at tractor and farm machinery test, Alexandria, Egypt. In this article, all performance parameters of Ultrasonic-Hydrogen Electrolyzer System (UHES) are carried such as the rate of hydrogen production, specific energy consumption and system efficiency under different number of electrodes, waveforms and wave frequency. The results showed that the hydrogen production rate was increased by using UHES under the triangular waveform at 25 kHz signal frequency.*

**Keywords:** waveform, ultrasonic, hydrogen production, and electrolyzer.

## 1. INTRODUCTION

Due to the rapidly increase in energy consumption, which is considered to be the most promising investment sectors in conjunction with the high annual increase of population. The energy demands will be tripled by 2050, as the population increased to 8-9 billion [1]. Thus, it is essentially for the governments to direct investments towards the field of power generation. On the other hand, hydrogen and electricity together represent one of the most promising ways to realize sustainable energy, whilst fuel cells provide the most efficient conversion device for converting hydrogen into electricity [2]. Moreover, the purified hydrogen and oxygen can be used in fuel cells (to produce direct current electricity) and catalytic burners (for heating and cooking) without poisoning or damaging the noble metal catalyst materials [3]. It can used as a fuel in internal combustion engines either pure or mixed with other hydrocarbon fuels [4]. In addition, hydrogen can be used as a sole fuel in spark ignition engine, either by carburetion or by directs injection [5]. So [6] summarized that the hydrogen as a fuel is a great source of energy that could be used in different applications including space industry, fuel cells, rockets, pumping and heating and more. Currently the majority of hydrogen comes from steam reforming of natural gas and partial oxidation of hydrocarbons since other techniques are not economically justified. The majority of technologies to produce hydrogen such as coal gasification, biomass processing etc. are not either sustainable or they yield hydrogen in the amount needed. However, hydrogen is not available on Earth in free form; the production process is representing a major part of the final price of hydrogen [7]. Due to the hydrogen characteristics, researchers made focusing attention on hydrogen as an alternative fuel. The electrolysis of water as a hydrogen production method, accounts for 4%-5% of global production, when combined with the ultrasound, the grouping is said to have increased mass and energy transfer consequently higher hydrogen generation [8]. Water electrolysis is used to produce hydrogen where electric current passes through water resulting in splitting water into hydrogen and oxygen [9]. Approximately, a minimum voltage of 1.23 V is required to be applied to a water molecule at laboratory conditions to break the bonds between hydrogen and oxygen atoms. This voltage is also known as the equilibrium voltage of water. However, much higher voltage levels are used in industrial electrolysis cells. The excess voltage is referred to as the “over potential” of the process reaction [10]. While, the electrolysis cells have an average hydrogen production efficiency of about 80% [11]. It is still further away from commercial use because of highly energy consumption and very costly to produce. There are several possible modifications can be done on electrolysis cells to minimize electrical power dissipation that used for hydrogen production. Can be reduced the power consumed in the hydrogen electrolytic production by targeting the resonant frequency of the water electrolysis cell [12]. By using ultrasonic waves by water, electrolysis increased the hydrogen production efficiency by 4.5% but it does not appear economical. When neglecting the extra power for ultrasonic waves, results still show better efficiency [13] and energy efficiency by 1.3% [14]. Also the hybrid, action between UV-visible electromagnetic radiation and 38 kHz ultrasound waves in producing hydrogen from a water/ethanol solution has an appreciable synergistic effect [15] and [16]. AC voltage is more favored than DC voltage for the production of hydrogen with less energy input. The optimal frequency is 2.0 kHz. The hydrogen production rate is also affected by the input waveform and decreases as following: sinusoid triangular > sinusoid > ramp > square, whereas the sinusoid waveform shows the highest energy efficiency [17]. In addition, [18] researched the effects of the ultrasound on an electrolysis cell where the energy efficiency was considerably enhanced. The hydrogen production efficiency was improved by a range between 5%-18% at high current density while the efficiency of oxygen gas decreased. Furthermore, the ultrasound reduced the values, which helped the electrolysis consume less energy compared to the silent case. The energy saving achieved.

The objectives of this study was to evaluate the design of ultrasonic system with different types of the appropriate shape and frequency of an ultrasonic wave through a series of performance indicators in order to establish (1) system efficiency and energy consumptions and (2) the rate of hydrogen under the different system settings.

## 2. MATERIALS AND METHODS

The main experiments were carried out in the Power and Energy laboratory at Tractor and Farm Machinery Test and Research Station Alexandria Governorate. A model manufactured and developed to determine the optimal configuration and the operation conditions for the hydrogen electrolyzer by using an ultrasonic technique.

### 2.1 Design and construction of the (UHES) system

The UHES used in this study is shown in figure 1. The UHES was consisted mainly of water electrolyzer unit, Ultrasonic Generator Unit and Power Amplifier unit.


**Figure 1. Ultrasonic-Hydrogen Electrolyzer System (UHES)**

#### 2.1.1. Water electrolyzer unit

The water electrolyser unit consisted mainly of analyzing unite and water trap.

#### 2.1.1.1. Analyzing unit

Figure 2 shows the water electrolysis system. The cells made from Stainless steel grade 310 plates with tabs on one end (anode and cathode electrodes) with a thickness of 0.9 mm and surface area of 200 $cm^2$, activity surface area of (5.5×16 cm) 88 cm2. The electrodes which separated by a rubber sheet of 2 mm were placed between the cells. Stainless steel metal sheet was chosen for its corrosion resistance to caustic electrolyte and long- lasting value.

The electrodes separated by a rubber sheet and assembled between two shelter plastic sheets (160 × 240 × 10 mm) by 10 stainless steel screw was recapping w4ith polystyrene tube. Two clusters electrode plates were placed, 11 for the anode and 11 for the cathode. The hydrogen remains separate from the bubbles, which produced from the positive electrode (anode) and exit on the opposite side.

#### 2.1.1.1. Bubblers (water trap)

Hydrogen scrubbed by passing it through a water bubbler column. The scrubbing bubblers was made from a vertical plastic tube with end caps (figure 3). A pair of public nozzle was joined into holes drilled inside bottom caps of acrylic plastic tube, using methylene chloride solvent. The bubblers were filled about two-third full with water, the one-third empty of water used as a product storage system or the electrolyzer.

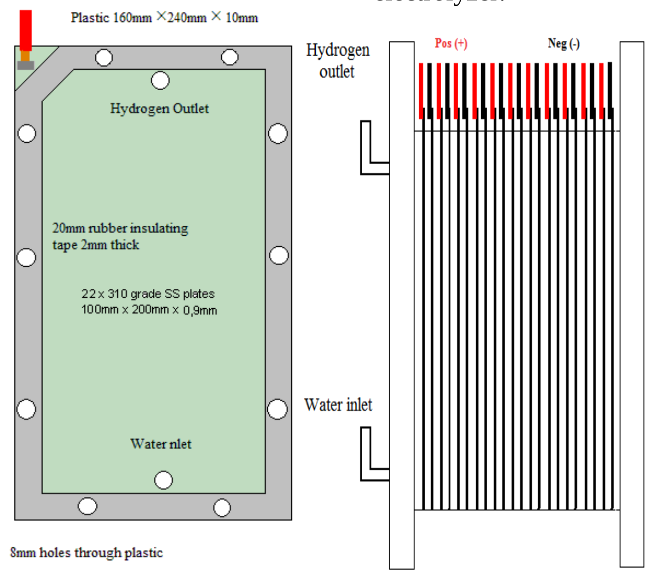


**Figure 2. The water electrolyzer**

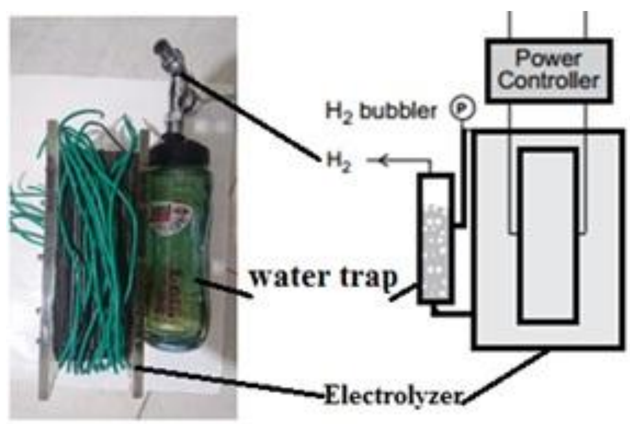


**Figure 3. Bubblers (water trap).**

#### 2.1.2. Ultrasonic Generator Unit (Arduino Waveform Generator)

The Arduino is open source hardware where the hardware schematic is open anybody can use those schematic to develop their Arduino board and distribute. Arduino board can act as a stand-alone system with capabilities to take inputs, process the input and then generate a corresponding output. It is through these inputs and outputs that the Arduino as a system can communicate with the environment. The Arduino boards communicates with other devices using digital input/output analog input/output standard communication ports like USB. There are many required waveform and frequencies can be generated like sine wave, saw tooth wave square wave and triangular wave with variable frequencies. In this study used a variable frequency generator from 1Hz to 50 kHz with the help of Arduino (Fig. 4).


**Figure 4 Arduino waveform Generator.**

### 2.1.3. Power Amplifier unit

Fig. (5) shows the schematic circuit diagram of ultrasonic power amplifier with output power of more than 1000 watt Power amplifier circuit with high power uses 3 channel MOSFET's in the output stage alone gives about 400Watt power. Band switch (SW1) was used to select the input signal from signal generator to power amplifier (without ultrasonic, Square, Triangular and Sine) and (SW2) used to select the frequencies (20, 25 and 30 kHz) while (RV4) to select the number of electrodes was attached.

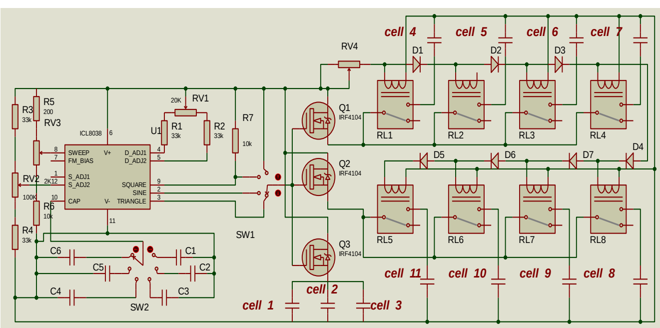


**Figure 5. The schematic circuit diagram of ultrasonic Power Amplifier**

## 2.2 Experimental Procedure

When water molecules vibrate, they tend to become unstable. At the same time, an electrical current is passed through the water, between the electrolyzer plates, in pulses occurring at the resonant frequency of water. It is well known that water will separate into hydrogen and oxygen gas in the presence of an electrical current (hydrolysis).

At the start filled the electrolyzer and bubblers with water to make sure of the electrodes are fully covered with water. The electrodes connected to the power supply. The experiments were divided into two parts: The first part, the pulses generator and a power amplifier are used to generate alternating current, with different waveform and the frequencies to operate the electrolyzer. The second part, the DC power supply is used to operate the electrolyzer.

The experimental procedure is measured the total hydrogen production every 15 minutes at certain voltage amplitude 12V with frequencies (0, 20, 25, and 30 kHz), and waveform shape (DC, sine, square and triangular), and so measure the average temperature of the water inside electrolyzer.

The UHES was examined as a function of change in the following parameters:

•Three different waveforms (Sine, Triangular, and Square waves).

•Three different frequencies (20, 25, and 30 kHz).

•Different the number of the electrodes (2 to 22 electrodes).

## 2.3 Performance evaluation of system.

### 2.3.1. Hydrogen production rate.

The hydrogen production rate ($f_{H2}$) was volumetrically measured by cumulated hydrogen per replication under laboratory conditions using water displacement metering system (Fig. 6) the hydrogen production was recalculated at the standard conditions (0 ˚C and 1 bar) to adjust the volume of hydrogen production. Hydrogen production rate ($f_{H2}$) for the Ultrasonic-Hydrogen Electrolyzer System was calculated using Eq. 1 [19].

$$f_{H2}\left(\frac{Nm^3}{h}\right)=\frac{Vtr}{t} \quad (1)$$

Where Vtr is total hydrogen production Volume at standard conditions of 0°C, 101.325 kPa, $Nm^3$ and (t) is operational time, h.

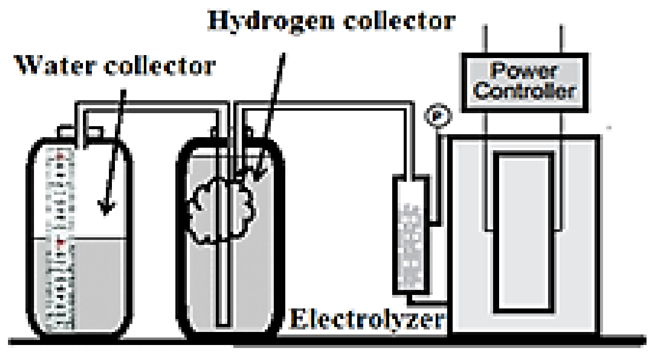


**Figure 6 The water displacement system.**

### 2.3.2. The specific energy consumption

The specific energy consumption (CE) of hydrogen during experiment at different operation system was expressed in kWh/Nm3, and calculated according to Eq.2 [20].

$$C_E = \frac{\int_0^{\Delta t} N_{cell} \times I_{cell} \times V_{cell}\, dt}{\int_0^{\Delta t} f_{H2}\, dt} \quad (2)$$

Where:

$N_{cell}$ is the number of cells that constitute the electrolysis module,

$I_{cell}$ is the cell current in A,

$V_{cell}$ is the cellvoltage in V,

$f_{H2}$ is the hydrogen production rate in $Nm^3/h$.

### 2.3.3. Electrolyzer efficiency

Electrolyzer efficiency (η_E ) represents the ratio between the energy contained in the produced hydrogen relative to

Higher Heating Value (HHV) of hydrogen (3.54 kWh/Nm$^3$) and the energy consumption CE in kWh/Nm3 [20].

$$\eta_E = \frac{HHV\ of\ H_2}{C_E} \times 100 \quad (3)$$

## 3. RESULTS AND DISCUSSION

### 3.1. Hydrogen production rate:

The UHES hydrogen production rate is significantly affected by many operational parameters such as the number of electrodes, waveforms and the signal frequencies. Fig. 7 shows the effect of the number of electrodes on UHES hydrogen production rate from Fig. 7, it can be observed that, the hydrogen production values increase with an increase of number of electrodes under all signal frequency and waveform. Obtained data shows that increasing number of electrodes from 2 to 10 electrodes, increased production rate from 0.018 to 0.100 Nm$^3$/h, under without ultrasonic waveform. While under Sine waveform hydrogen production increased from 0.061 to 0.320, from 0.075 to 0.336 and from 0.067 to 0.310 Nm$^3$/h at 20, 25 and 30 kHz signal frequencies respectively. Moreover, under triangular waveform hydrogen production from 0.077 to 0.355, from 0.094 to 0.388 and from 0.091 to 0.378 Nm$^3$/h at 20, 25 and 30 kHz signal frequencies respectively. In addition, under square wave form hydrogen production Increase from 0.070 to 0.341, from 0.081 to 0.386 and from 0.076 to 0.375 Nm3/h. The ultrasonic wave reduces the polarization impedances. Notably, ultrasonic power correlates positively with impedance reduction. In addition, ultrasound accelerates the deviation of bubbles from the electrode surface and instantly reduces the occurrence of phenomena related to polarization impedance. These results were in agreement with that obtained by [13] and [14].

### 3.2. Specific energy consumption

Fig. 8 represents the UHES specific energy consumption under different treatments under study. It is evident from Fig. 8 that the specific energy consumption values increased with increase in number of electrodes at different leaves of signal frequency and waveform. Results of data analysis showed that the increasing number of electrodes from 2 to 10 electrodes, increased energy requirements from 6.05 to 30.24 kWh, under without ultrasonic waveform. While under Sine, waveform energy increased from5.395 to 27.000, from 5.630 to 26.880 and from 5.900 to 26.940 kWh/Nm$^3$ at 20, 25 and 30 kHz respectively. In addition, under triangular waveform energy increased from 5.552 to 22.876, from 5.608 to 23.040 and from 5.652 to 22.589 kWh/Nm$^3$ at 20, 25 and 30 kHz signal frequencies respectively. In addition, under square waveform energy requirements from 7.498 to 30.240, from 7.502 to 27.840 and from 6.276 to 28.420 kWh/Nm$^3$ at 20, 25 and 30 kHz signal frequencies. When water molecules vibrate by the frequency, they tend to become unstable. This vibration will cause the water molecules to disassociate into hydrogen and oxygen gas. These results were in agreement with that obtained by [18].

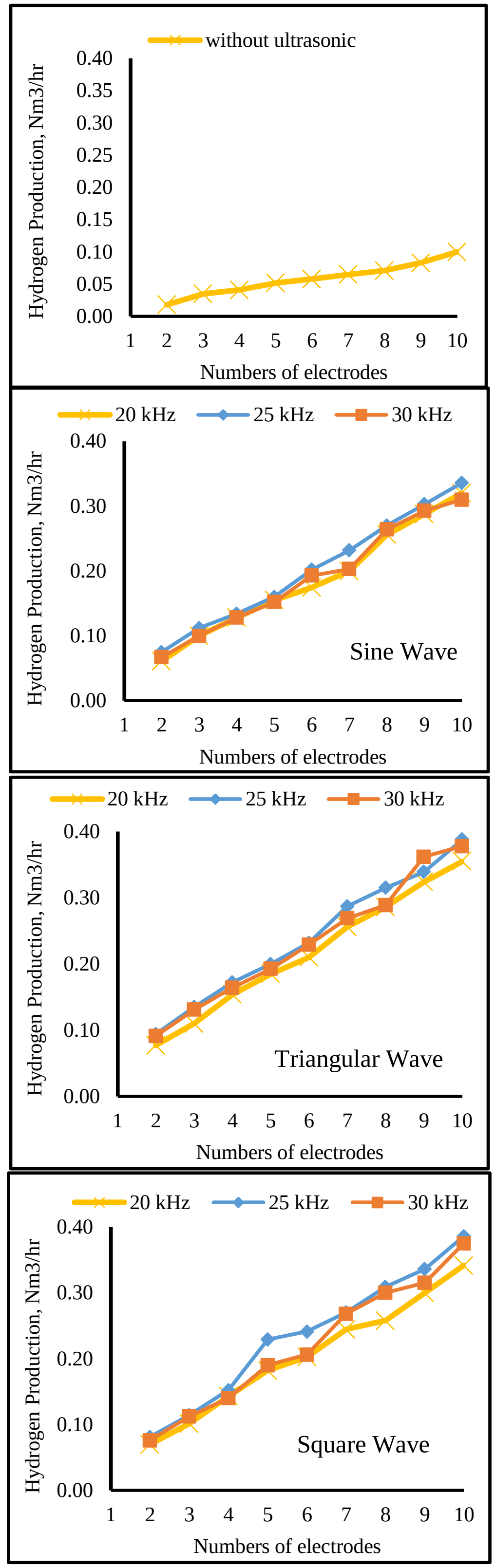


**Figure 7 Hydrogen production rate under different treatments**

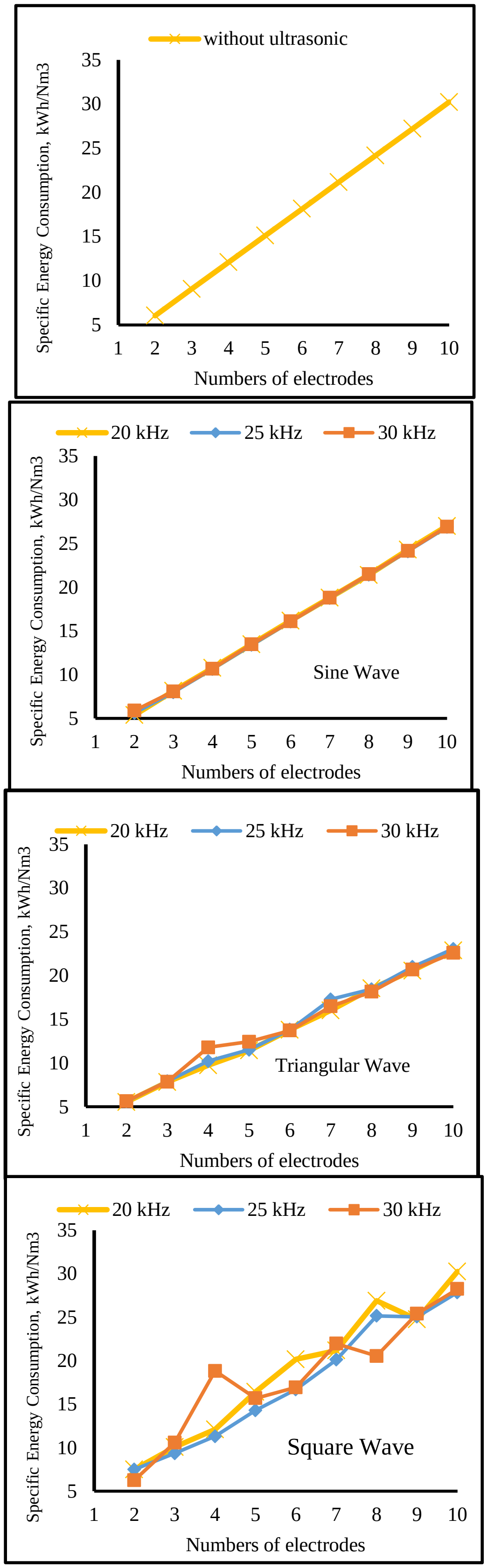


**Figure 8 Hydrogen production rate under different treatments**

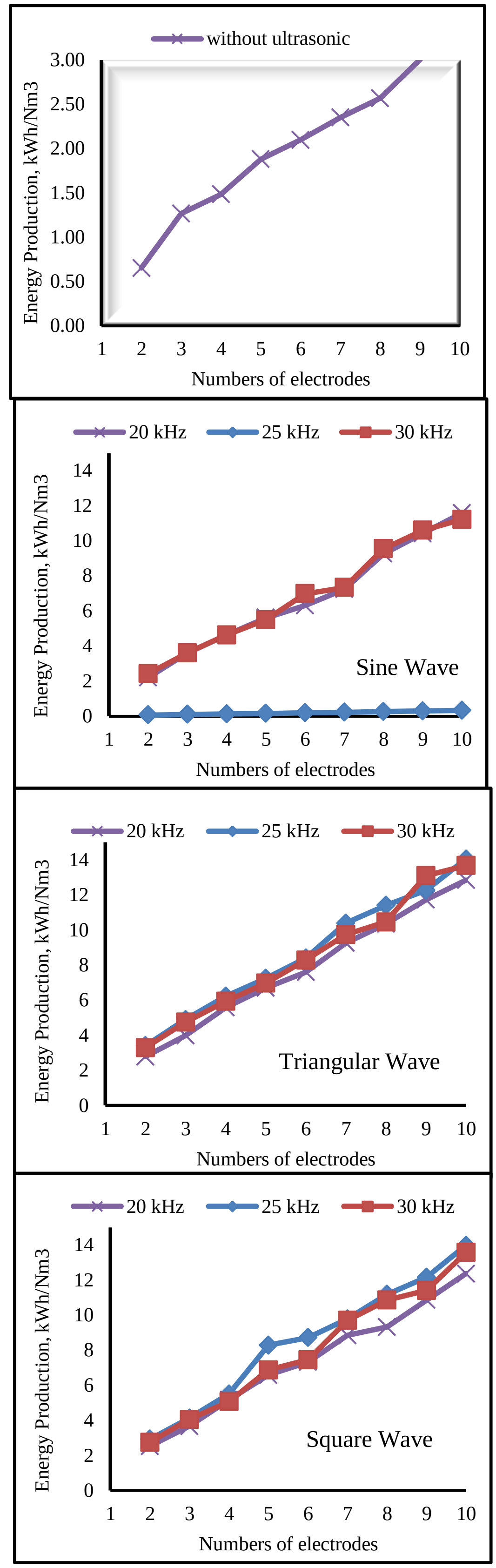


**Figure 9 Energy production under the different treatments**

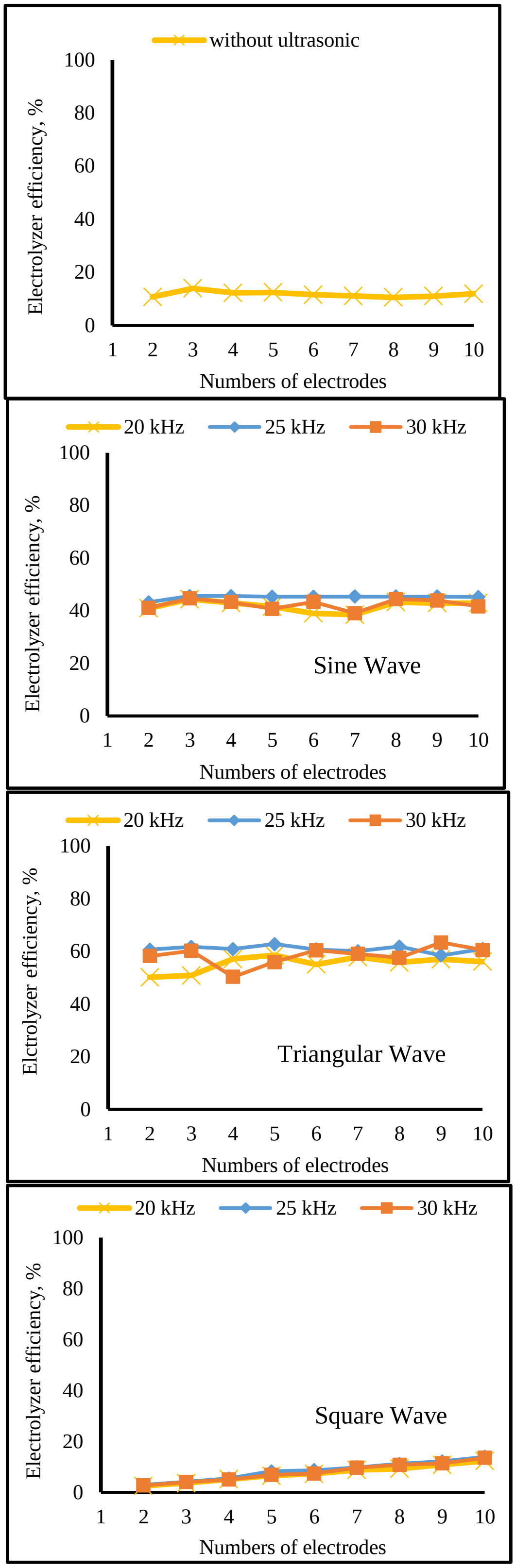


**Figure 10 Electrolyzer efficiency under the different treatments**

### 3.3. Energy Production

Figure 9 represents the UHES energy production under different treatments under study. It is evident from Fig. 9 that the energy production values increased with increase in number of electrodes at different levels of signal frequency and waveform. The energy production values increased by increasing the number of electrodes at any signal frequency and any waveform. Obtained data show that increasing numbers of electrodes from 2 to 10 electrodes, increased energy production from 0.65 to 3.62 kWh/Nm$^3$, under without ultrasonic waveform. While under Sine waveform energy requirements from 2.207 to 11.578, from 2.431 to 12.156 and from 2.424 to 11.216 kWh/Nm$^3$ at 20, 25 and 30 kHz signal frequencies respectively. In addition, under triangular waveform energy production increased from 2.786 to 12.844, from 3.401 to 14.038 and from 3.292 to 13.676 kWh/Nm$^3$ at 20, 25 and 30 kHz signal frequencies respectively. In addition, under square waveform energy production increased from 2.527 to12.353, from 2.931 to 13.965 and from 2.750 to 13.568 kWh/Nm3 at 20, 25 and 30 kHz signal frequencies. These results were in agreement with that obtained by [17].

### 3.4. Electrolyzer efficiency

The effect of the number of electrodes, waveforms and signal frequencies on UHES efficiency is shown in Fig. 10. It is evident from Fig. 10 that the electrolyze efficiency was found to increase with increase in number of electrodes at different values of signal frequency and waveform.

Obtained data show that increasing number of electrodes from 2 to 10 electrodes increased efficiency from 10.77 to 11.96 %, under without ultrasonic waveform. While under Sine waveform efficiency increased from 40.908 to 42.880, from 43.185 to 45.225 and from 41.086 to 41.633 at 20, 25 and 30 kHz signal frequencies respectively. In addition, under triangular waveform efficiency increased from 50.178 to 56.146, from 60.644 to 60.928 and from 58.252 to 60.543 at 20, 25 and 30 kHz signal frequencies respectively. In addition, under square waveform efficiency increased from 33.7 to 40.851, from 39.064 to 50.163 and from 43.816 to 48.044 % at 20, 25 and 30 kHz signal frequencies respectively. These results were in agreement with that obtained by [14].

## 4. CONCLUSIONS

In this work, an ultrasonic water electrolyzer was designed and constructed to produce hydrogen gas from the experimental results, it can be seen that the triangular waveform has the maximum hydrogen production followed by sine waveform. The gain in total hydrogen production rate was 0.388 Nm3/h, specific energy consumption was 23.040 kWh/Nm$^3$, energy production was 14.038 kWh/Nm3and system efficiency was 72 %.

## 5. REFERANCE

[1] Snow, N., "World Energy Council report identifies" global issues trends - Oil & Gas Journal, http://www.ogj.com/articles/print/\olume(2017).
[2] Final Report of the High Level Group, (2003).

[3] Pyle, W. J. Healy and R. Cortez, “Solar Hydrogen Production by Electrolysis” Home Power #39 • February / March 1994.

[4] Das, L.M. and Near-term, Introduction of Hydrogen engines for automotive and agriculture application. Int. J. Hydrogen Energy, **27**:479-87 (2002).

[5] Küleri, K. A., “In the lean burn spark ignition engines the effect of the hydrogen addition on the cyclic variability and exhaust emission” (In Turkish), Master Thesis, Atatürk University Institute of Science, Erzurum, 45–55(2011).

[6] EIA, “Coal Reserves Data Base”, U.S Energy Information Administration, Washington (2004).

[7] Hydrogen Pathway, Welcome to the Roads2HyCom Hydrogen and Fuel Cell Wiki: Cost Analysis; 18.11.2011; Available from: www.ika.rwth-aachen.de/r2h/index.

[8] Zhang, K. Z. D., "Recent progress in alkaline water electrolysis for hydrogen production and applications," Process in Energy and Combustion Science, **36**, 307-326 (2010).

[9] Smolinka, T., "Fuels– Hydrogen Production Water Electrolysis", Reference Module in Chemistry, Molecular Sciences and Chemical Engineering, from Encyclopedia of Electrochemical Power Sources, pp. 394-413(2012).

[10] Matsushima, H, T. Nishida, Y. Konishi, Y. Fukunaka, Y. Ito and K. Kuribayashi, Electrochim. Acta, **48** (2003) 4119.

[11] Mazloomi, K., N. B. Sulaiman and H. Moayedi5, "Electrical Efficiency of Electrolytic Hydrogen Production". Int. J. Electrochem. Sci., **7**, 3314 – 3326 (2012).

[12] Mazloomi, K., N. B. Sulaiman, H. Moayedi5, "An Investigation into the Electrical Impedance of Water Electrolysis Cells - With a View to Saving Energy" Int. J. Electrochem. Sci., **7**, 3466 – 3481 (2012).

[13] Ming, Y. L. and L. W. Hourng, "Ultrasonic wave field effects on hydrogen production by water electrolysis" Journal of the Chinese Institute of Engineers **37**,(8), 1080–1089 (2014).

[14] Zadeh, S. H., “Hydrogen Production via Ultrasound-Aided Alkaline Water Electrolysis,” Journal of Automation and Control Engineering. **2**, (1), 103-109 (2014).

[15] Penconi, M., S. Rossi, S. Ortica, S. Elisei, and B. N. Gentili, “Hydrogen Production from Water by Photolysis, Sonolysis, and Sonophotolysis with Solid Solutions of Rare Earth, Gallium and Indium Oxides as Heterogeneous Catalysts” Sustainability journal, **7**, 9310-9325 (2015).

[16] Marta P., R. Federico, O. Fausto, E. Fausto, and L. G. Pier., “Hydrogen Production from Water by Photolysis, Sonolysis, and Sonophotolysis with Solid Solutions of Rare Earth, Gallium and Indium Oxides as Heterogeneous Catalysts Sustainability”, **7**, 9310-9325; doi: 10.3390/su7079310 (2015).

[17] Zou, J. J., Y. Zhang, and C. Liu, “Hydrogen production from dimethyl ether using corona discharge plasma” Journal of Power Sources **163** 653–657 (2007).

[18] Sheng, D. L., C. C. Wang and, C. Y. Chen, "Water electrolysis in the presence of an ultrasonic field," Electrochimica Acta, **54**, (15), 3877-3883, (20090.

[19] Gosch, A.; M. Hildegrate, W. Ursula and J. Walter, “The anaerobic treatment of poultry manure”. Animal Res. And Dev., **17**: 62-73 (1983).

[20] Alfredo U, M. Luis, A. Gand, and Sanchis, "Hydrogen Production from Water Electrolysis: Current Status and Future Trends" (2012).


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